RECYCLE: A Computerized Planning Tool to Improve Municipal Solid Waste Management[1]

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ABSTRACT. **RECYCLE is a simulation model designed to assist municipal decision-makers in beginning the planning process to determine what options in municipal recycling are appropriate for their communities. Its structure can be adapted to the vast array of municipal solid waste handling systems found around the country. It simulates a large number of options suitable for each type of municipal system and chooses the ones most appropriate for community officials to examine in greater detail. It reflects the kinds of questions addressed in municipal solid waste management and is also appropriate for communities picking up their own refuse, contracting with specific private trash haulers, and having strictly private trash pickup. Model runs have already influenced the structure of recycling programs in northeast Ohio, and the model has generated interest in several other areas.**

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INTRODUCTION

Solid waste management is one of the largest items in a municipal budget. An American family discards over two tons of refuse each year; a typical city of 50,000 can expect to spend on the order of $2.5 million annually to pick up, haul, and dispose of this refuse (Cuyahoga County Regional Planning Commission 1980). About 20-25% of this refuse is potentially recyclable (Table 1), indicating a significant possible savings for communities that undertake serious recycling programs (Office of Solid Wastes 1977). But every community is different. Recycling has so many site-specific aspects that it is never obvious *a priori* what kind of program is most appropriate for a particular city. Thus, a community will seldom be able to adopt a program identical to one that has worked for a neighbor (Clapham 1983). In addition, some of the most important factors that enter municipal decision-making are "soft" variables like municipal image, nature of work rules with the service workers' union, personal preferences of the municipal government, and so on.

RECYCLE is a generalized tool that clarifies the potential roles for recycling in municipal solid waste (MSW) management programs and facilitates the early stages of the planning process. It allows planners to consider a vast range of potential options for recycling without overwhelming them with vast amounts of information that they do not need to know about options which are infeasible for the community. It provides a rapid, efficient mechanism for considering a broad range of possible options in the context of individual communities and for identifying a tractable number of feasible alternatives for further and detailed consideration. It is a fairly simple model whose assumptions and calculations can be verified by planners normally inclined to distrust computer analyses. It can also provide sufficiently accurate information to be useful as a point of departure for detailed planning.

STRUCTURE OF 'RECYCLE'

The model is summarized mathematically in the appendix. It consists of several blocks that perform four functions sequentially (Fig. 1). The first "describes" the MSW system of the community. It works interactively with the user to gain information about the site-specific features of the city and then avails itself of other data needed to describe MSW management in more general terms. Finally, it characterizes the potentially recyclable components of the MSW stream.

The second block examines 24 different options in which the primary responsibility for recycling rests on the shoulders of the householder. Twelve of these are dropoff-donation centers (i.e., what are generally

TABLE 1

Makeup of typical municipal solid waste (MSW) in the United States, 1971–1975

Commodity	Percentage in MSW	Ease of recycling from MSW
Paper	34.6 – 43.0	High
Glass	12.0 – 13.3	High
Ferrous Metals	10.2 – 10.8	High
Aluminum	0.8 – 1.0	High
Other Metals	0.4 —	Low
Plastics	4.2 – 4.6	Low
Rubber and Leather	3.3 – 3.8	Low
Textiles	1.7 – 2.1	Low
Wood	4.5 – 4.9	Low
Food Wastes	20.8 – 22.7	Nil

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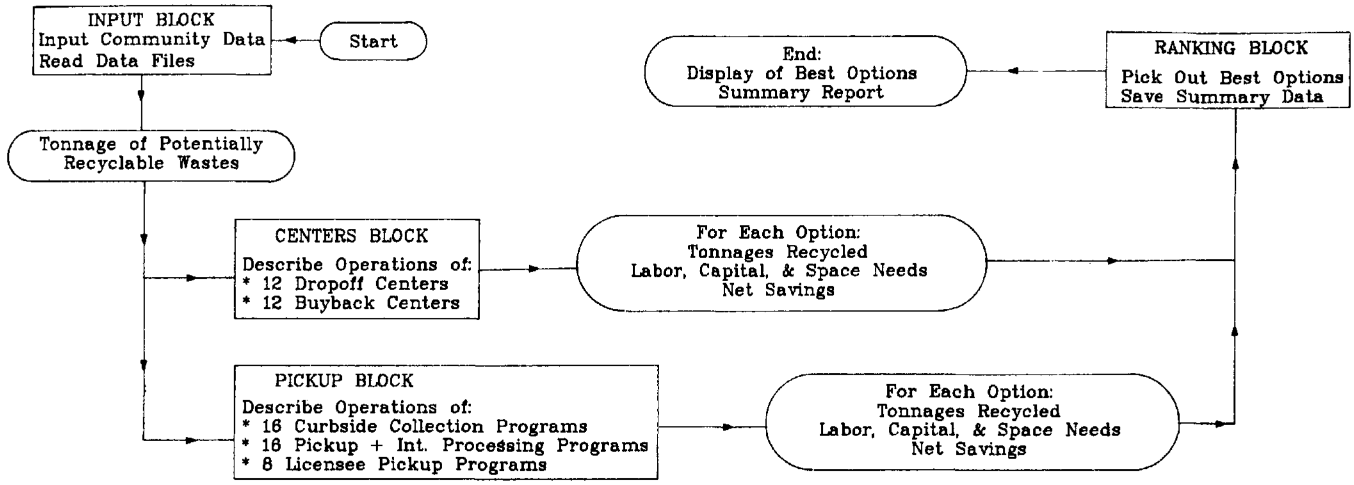

FIGURE 1. Simplified flow chart showing functions of blocks within the recycling computer model.

termed "recycling centers"); the other 12 are buyback centers in which recyclable materials are purchased from householders.

The third block considers 40 different configurations of pickup programs in which primary responsibility remains with the city, and recycling is integrated into the solid waste management program of the city. Sixteen involve simplified municipal pickup, in which the municipality collects the recyclables and sells them. Sixteen involve some "intermediate processing", in which the municipality collects the materials and processes them to some degree prior to sale to increase the sale value of the recyclable materials. The last eight options explore the implications of the arrangement of a city with a nonprofit licensee to collect recyclables independently of routine municipal pickup.

The final block ranks the different options on the basis of the "bottom line," or net savings to the community, and picks from each of the five basic categories two that promise the greatest net savings to the community, and that are most likely to be suitable for further consideration. Results presented to the user include net savings from adopting a recycling program, as well as the constitutent costs and credits which make up this net saving. It then stores the basic data for all 64 options in a reference file and prepares a summary report of 15 to 17 pages containing the implications of each of the options in language that a municipal decision-maker can understand and work with.

BLOCK I: INPUT. The input block initializes the model. It allows city-specific data to be entered into the model, enables the user to change certain numerical data so that they are more appropriate for his or her community, and reads in basic parameters. After initializing the model, it displays the assumptions used during the model run, while the calculations and sorting operations are being performed.

The block begins with an interactive section in which the computer asks the user for the community-specific information that adapts the structure of the model to local circumstances. The questions asked by the model are summarized in Table 2. More details on the information required by the model are contained in the technical documentation of the model (Clapham 1984a). In its final step, the input block calculates the tonnage of the easily recyclable commodities.

BLOCK II: CENTERS. The "centers" block analyzes 24 typical options available at recycling or buyback

TABLE 2

Questions asked by the interactive section of RECYCLE

1. How many residents live in your municipality?
2. What is the community's educational level?
3. How many households do you collect refuse from?
4. How many households are not collected (e.g. apartments)?
5. How many tons of Municipal Solid Waste do you collect annually?
6. How many miles of city streets does your city have?
7. How many daily routes does your city have for garbage pickup?
8. What size crew do you use in garbage trucks in your municipality?
9. What size garbage trucks, in cubic yards, do you use?
10. Are your garbage truck crews paid by the hour or by the route?
11. Are there streets in your city along which garbage trucks must routinely back up or turn around in extremely restricted areas?
12. Do you use standard rear-loading garbage trucks?
13. What is the composition of your municipal solid waste?
14. What market prices are available for your recyclable commodities?
15. What is the typical HOURLY wage of your service workers?
16. How many hours per week does a typical service worker work?
17. Do you have a transfer station for municipal solid wastes?
18. What is the average cost per ton of municipal solid waste pickup and transport to your transfer station, if you have one, or directly to your landfill, if you do not have a transfer station?
19. What is the average cost per ton of hauling minicipal solid wastes from your transfer station (if you have one) to your landfill?
20. What is the average tipping fee per ton for your refuse.
21. Do you believe that you will be able to get facilities to store recyclables in your recycling program free, either by donation or by agreement with your market? These include Gaylords, dumpsters, roll-off containers, etc.
22. Do you believe that you will be able to obtain free basic processing machinery to handle recyclables in a recycling center, either by donation or by agreement with your market?
23. Do you believe that you will be able to get free space to locate a recycling or buyback center?
24. Do you believe that you will be able to get free space to locate the storage and transfer facilities needed for a curbside pickup program?
25. Do you believe that you will be able to get free space for trucks or trailers needed for certain options involving curbside pickup? These would likely be at your service center or transfer station.
26. Are you satisfied that all data you have entered are correct?

centers. It establishes a three-dimensional "options matrix" defining the set of options available at different kinds of centers. The dimensions are center types (i.e., standard dropoff-donation or buyback center), hours of center availability, and commodities accepted (Table 3).

This block first calculates the anticipated collections of recyclable wastes for each commodity collected via each of the 24 options considered, based on total tonnage of potentially recyclable MSW and the appropriate participation rate. The participation rate is typically a function of the educational level of the community (SCS Engineers 1974a, 1974b). The total tonnage recycled via each option is calculated by summing the collections of all commodities. Sales for each commodity are determined by multiplying the tonnage collected by its sale value. For buyback centers, the model also calculates the payout by the center to purchase recyclables. This is equal to the tonnage collected times the prices paid for each commodity in a buyback center; these prices are assumed to be a proportion of the market value of each commodity. Total sales income and buyback expenses are calculated by summing sales over all commodities for each option within the matrix.

Next, the model calculates savings in MSW handling costs to the community in which centers are located. Recycled wastes do not have to be processed through the usual service functions of the community. The resulting savings are credited to the calculated "income" stream of the recycling program. Collection expenses decline slightly, since service workers can complete their rounds having spent less time picking up refuse. Likewise, recycled wastes never appear at the transfer station of the municipality. They do not have to be loaded into specialized packer trucks and hauled to a landfill; therefore, they do not contribute to the wear and tear on the transfer station or its trucks. These expenses are reduced directly in proportion to the amount of MSW removed from the waste stream. Finally, recycled wastes do not have to be landfilled. The tipping fee that would have been paid to dispose of the recycled wastes is credited to the income stream as a savings.

Costs considered for recycling and buyback centers include capital, labor, and maintenance. Capital includes storage facilities and machinery, and is proportional to the tonnage collected. The annual costs of capital are allocated to the balance sheet on a straight-line basis over an estimated lifetime. Labor and space needs are also related to tonnage handled, subject to a minimum of one worker and minimal space in order to allow the center to function.

Finally, the model calculates net total income and the total costs of the center. Total income is equal to the sum of the savings in tipping, pickup, and hauling, as well as the income from sales. The cost to the center is buyback expenses incurred (if any), the depreciation of storage and machinery, and the costs of labor and space. The net savings due to the recycling program are equal to the gross income less the gross costs.

BLOCK III: PICKUP. The pickup block considers those recycling options for which municipalities retain responsibility for handling recyclable commodities by incorporating recycling into their municipal service program, whether by simple curbside pickup and immediate sale, curbside pickup followed by some intermediate processing, or by licensing pickup of recyclables to another party. As with the centers block, the pickup block defines a three-dimensional options matrix (Table 4).

The operation of the pickup block parallels that of the centers block. The model first calculates the anticipated collection of each commodity in each option in the matrix, based on the potentially recyclable tonnage and expected participation rate. The tonnage of material diverted from the waste stream via each option is then determined by summing over the range of commodities collected. Sales of materials are equal to the recyclable materials actually collected times the sale value of those materials. Total sales for each option are calculated by summing over all commodities.

Savings in pickup, hauling, and tipping are calculated as in the centers block, except that no collection credit is given when truck-mounted racks or trailers are used. In these cases, all MSW that would normally have been picked up as refuse is picked up by the same crew on the same truck, but separated into nonrecyclable and recyclable components. Recycling systems using separate

TABLE 3

Dimensions of the options matrix for centers

Type of Center

1. Recycling center (dropoff-donation)
2. Buyback center (consumer is paid for recyclables)

Access to Center

1. Center is open all week (6 days per week, 8 hours per day)
2. Center is open weekends only (2 days per week, hours per day)
3. Center is open once per month (2 days per month, 10 hours per day)

Commodities Handled by Center

1. Newspaper only
2. Newspaper, mixed-color glass, mixed metals
3. Newspaper, separated-color glass, separated metals
4. Complex mixture of commodities

TABLE 4

Dimensions of the options matrix for pickup program

Type of Pickup Program

1. Municipal curbside pickup without further processing
2. Municipal curbside pickup with intermediate processing
3. Curbside pickup by outside party licensed by municipality*

Technique of Pickup

1. Same truck as refuse pickup, using racks mounted on the trucks
2. Same truck as refuse pickup, using trailers pulled behind trucks
3. Different truck than refuse pickup, but collection on the same day
4. Different truck than refuse pickup, with collection on different day

Commodities Handled by Program

1. Newspaper only
2. Newspaper, mixed glass and metals (i.e., collection as two commodities)
3. Newspaper mixed with glass and metals (i.e., collection as one commodity)
4. Newspaper, mixed-color glass, mixed metals

*The third party licensee is limited, of course, to pickup options involving separate trucks different from those used by the municipality for routine refuse pickup.

trucks are credited for collection savings by the refuse truck and then billed for the explicit cost of pickup by the separate truck.

Capital costs are also handled as in the centers block, with the addition of equipment related to the actual pickup of recyclables. This includes racks or trailers mounted on existing garbage trucks or separate trucks for recyclables pickup. For recycling systems using separate trucks, the number of trucks required must first be calculated; this is done on the basis of street mileage in the city, subject to a minimum of one truck. Recycled materials collected by municipalities are typically sold immediately. However, some communities may wish to beneficiate (e.g., separating paper from containers, glass from cans, aluminum from steel) materials to improve quality and market price. The capital costs of the equipment needed to do this "intermediate processing" are then calculated, and the corresponding annual costs included in the figures for those options involving intermediate processing.

Labor and space needs are quite different from those of the centers block, since the structure of the recycling systems depends on whether existing labor and trucks are used. The marginal cost of both in pickup programs using existing trucks is calculated by adjusting the basic labor cost of operating and garaging a garbage truck. The cost of pickup using separate trucks is based on the annual cost of operating one truck and the number of trucks needed for the program. Space needs are proportional to tonnage recycled and include space for intermediate processing equipment and garaging additional trailers and trucks needed for the actual pickup, as well as space to store materials.

Communities choosing to contract out recycling to another agency will not bear most of the direct expenses incurred by communities that pick up recyclables separate from refuse. Nor will they receive the income from sales. Their benefit is the reduction in costs of pickup, hauling, and tipping of recyclables diverted from the solid waste stream. To assure those savings, communities need to recognize that sales from recycling seldom cover the entire cost of pickup and management. A licensee assumes all of the costs of pickup and cannot use racks or trailers on existing garbage trucks. In return, the licensee receives only the income from commodity sales and does not benefit from savings in tipping fees or hauling costs. For this reason, cities using licensees will generally have to provide some financial support; the question is how much. The model assumes that cities that benefit by having a licensee diverting MSW from their landfills will contribute a portion of the tipping fee saved by the recycling program. In this way, they will continue to benefit financially from recycling, and the licensee is more likely to show a positive balance sheet.

Total income is, as before, equal to the savings from tipping, pickup, and hauling, plus income from sales. Total costs include the costs of capital, labor, space, and any subsidies to non-profit licensees. Net savings is equal to gross income less gross costs.

BLOCK IV: RANKING AND DISPLAY. The ranking module ranks the various options on the basis of effectiveness. "Effectiveness" in this context can mean several different things. The most meaningful (and the one used here) is net savings to the solid waste management bill of the community, although return on investment or amount of material recycled might also be appropriate criteria for decision making. The function of the ranking block is to cull the information derived by the previous modules and present up to 10 different options so that the user can understand what options are likely to be most appropriate for the community.

Operations are ranked within the five types of programs considered: recycling centers, buyback centers, curbside pickup without intermediate processing, curbside pickup with intermediate processing, and pickup by a licensee. The two most effective options for each basic

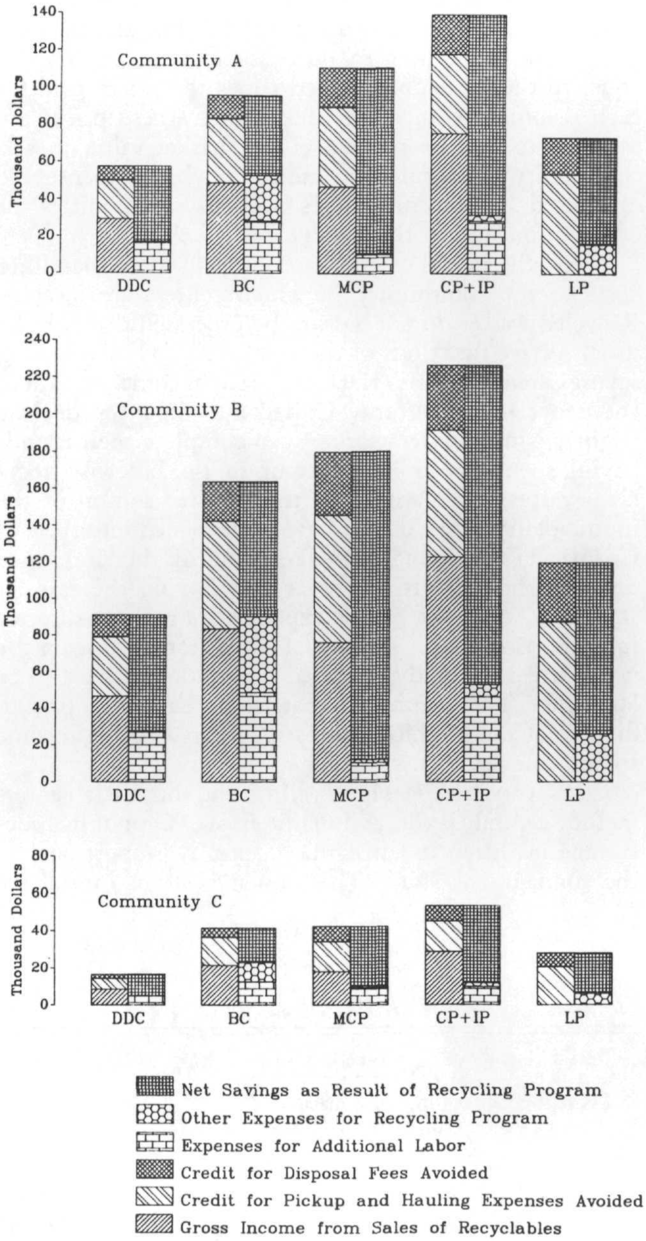

FIGURE 2. Graphic summary of the model runs for the three model communities. Income and credits are shown in the left-hand column for each option; expenses and net savings to the community are shown in the right-hand column. The five options shown are the preferred option in each of the five categories considered by the model: DCC, Dropoff/Donation Center; BC, Buyback Center; MCP, Municipal Curbside Pickup; CP+IP, Curbside Pickup plus Intermediate Processing by the Municipality; LP, Pickup of Recyclables by Licensee.

category are chosen on the basis of net savings. The key information from each option is displayed at the end of the model run. All 10 options and their associated net savings are shown on the terminal (Fig. 2), enabling the user to assess whether a different run should be made immediately to change some of the assumption used. This kind of "instantaneous feedback" may be a useful way for carrying out the early stages of the planning process interactively with this type of model. At the same time, this block prepares a report that includes all of the basic data calculated by the model for each feasible option chosen by the ranking block and corresponding descriptive text designed to assist the user in interpreting the calculations.

VALIDATION AND USE OF THE MODEL

RECYCLE is a fairly simple model. It does not have many decision boxes and does not attempt to simulate the decision process. The calculations are simple, and the parameter values are fairly well understood. Its strategy is to allow its structure to be adapted to the vast array of municipal solid waste handling systems found around the country, to simulate a large number of options suitable for each type of municipal system, and to choose the ones most appropriate for community officials to examine in greater detail. Validation was done for several key options with figures from actual recycling programs. Enough options need to be considered in the validation process so that all different structures and all parameters are verified with the experience of real communities. Several hundred communities around the United States have recycling programs that can be used to verify the structure and validate the numbers used. Justifications for the numbers are given in the detailed technical documentation prepared for the Office of Litter Control (Clapham 1984a).

An equally important sort of validation for a model intended to have a role in the public policy process is its effectiveness in assisting and improving decisions. When the existence of RECYCLE was announced in the trade literature (Clapham 1985b), it generated considerable interest. Copies of the program and its detailed documentation have been made available to individuals, consultants, and state or provincial solid waste authorities in over 12 states, four Canadian provinces, and the United Kingdom. Discussions with some of the people involved suggest that they have found the materials useful. It has already affected recycling programs in Cleveland Heights and Lakewood, Ohio, in very different ways. Both cities are inner-ring middle to upper-middle class suburbs that have been willing to make a commitment to recycling. Cleveland Heights has had a city-operated newspaper recycling program for several years, in which papers are picked up by city service workers with racks mounted on standard garbage trucks. An organization of citizens has been pushing the city to expand this program to include other materials as well; however, the city administration has been very resistant to change. The organization of citizens and the city both commissioned studies to assess the suitability of different approaches to multi-material pickup programs. Lakewood has long been interested in establishing a recycling center, but had not done so until fairly recently.

RECYCLE was applied to both cities. The analysis of Cleveland Heights demonstrated that the current newspaper operation based on rack-mounted curbside pickup was the second-best option within the municipal pickup category. The figures calculated by the model were essentially identical to actual data, so the credibility of the model was quite high. The first choice was an expanded multi-material pickup program similar in many ways to that recommended by the consultant to the citizens' group. As expected, this latter option picked out by the model had a substantially higher "bottom line." Nevertheless, RECYCLE pointed out that the existing recycling program was the second choice, and that larger savings to the city promised by multi-material collection entailed risks that the city was clearly unwilling to take. The group decided to delay pushing the city for change until developments in the recycling market were clearer.

The City of Lakewood was interested in opening a very basic recycling center accepting minimal materials from the public at some time in the future. The results from RECYCLE convinced Lakewood that there was a market for glass at the current time. A glass recycling center was subsequently established at the Lakewood transfer station. The experiences from this center were to be used to guide the city in any expanded recycling program. It has since added newspaper recycling at the transfer station and glass barrels at its fire stations.

RECYCLE has several characteristics that made it useful in these two cases. In Cleveland Heights, several consultants presented conflicting data and conclusions. The model was able to compare different approaches to recycling in a relatively straightforward and unbiased way. Most importantly, it was able to compare the proposed multi-material pickup program with the existing program virtually on a point-by-point basis, so that the citizens' group could clarify the benefits and the risks of changing the structure of the recycling program. It was significant (and unplanned) that RECYCLE picked out precisely the existing program as a very viable second choice. Its role was very different in Lakewood. Here, it brought together the basic data that needed to be considered so that they were meaningful to the Litter Coordinator of Lakewood, and it provided some documented alternatives that she could present to the Mayor.

MODEL OPERATION AND SAMPLE MODEL RUNS

To see how the model works, consider three communities. Community A is a suburb with a greater than average educational level and a population of 50,000. Most of the data are taken from Cleveland Heights, Ohio. Community B is a district in a central city with average education and a population of 100,000. It is based on the Old Brooklyn neighborhood of Cleveland, Ohio. Community C is a suburb with a less than average educational level and a population of 25,000. It is based on East Cleveland, Ohio. Many other types of cities could be analyzed, but these three should provide insight into the range of problems and opportunities facing real communities in the United States.

The three communities are assumed to have the same refuse composition. The MSW consists of 10.4% newspaper, 7.5% glass, 4.0% steel, and 0.3% aluminum. This is the composition of MSW measured at the Ridge Road transfer station in Cleveland, Ohio, and is a good estimate for actual MSW composition for an urban area

TABLE 5

Market values of recycled communities assumed for sample model runs

Commodity	Value (dollars per ton)
Newspaper	$ 30.00
Color-separated glass	35.00
Mixed-color glass	17.50
Steel	12.00
Aluminum	800.00
Mixed cans (steel and aluminum)	15.00
Mixed containers (cans and bottles)	13.00
Mixed recyclables (containers and paper)	10.00

in the Great Lakes area in 1980 (Bechtel, Inc. 1980). It would be useful to have more precise data for communities of different socioeconomic levels, since some other key variables are known to vary by economic or educational level. The data are not available, however. The market values of the recyclable commodities used in the analysis are given in Table 5. These numbers are average values for the Cleveland area in the early 1980's. Like most market values, these figures are subject to considerable fluctuation; they have been both considerably higher and lower. Other assumptions made for the model runs are summarized in Table 6. City-specific assumptions are derived from the communities for which the model communities are patterned; other assumptions are justified in the detailed documentation of the model (Clapham 1984b).

The results of the model runs are summarized in Table 7. Each column of numbers represents the optimal option for communities A, B, and C, respectively, as calculated by the model. The five parts of the table show results for dropoff-donation centers, buyback centers, municipal curbside pickup, municipal curbside pickup with intermediate processing, and licensee pickup, respectively. In addition to the net savings to the community, the table documents the tonnage of recycled materials for each option, proceeds from sales, credits for expenses foregone, and costs for labor, space, and equipment.

The table emphasizes the tremendous benefits of scale and the usefulness of a minimum community size for adequate support of a recycling program. Community C, with 25,000 residents, has 1/4 the population of Community B. Yet its net savings in dropoff-donation programs (i.e., the most popular approach) is 18% of that of community B. This is due to the lower educational level (and hence to a lower likelihood of participating in a recycling program) of community C, as well as the fact that the basic costs of a recycling operation impinge disproportionately on a small program when compared to a larger program.

Buyback centers provide a different result. In this case, the net savings to community C are actually a little over 25% of that of community B. The reason is that the opportunity to sell recyclables at a buyback center is relatively more attractive in the poorer community. It also raises the participation level to that of community C.

A similar case applies to recyclables picked up at curbside. Community C has a net savings about 16% of that of community B. As shown in Figure 2, the net savings to the communities are much more parallel to the volumes of materials collected than are the savings from recycling centers. The most likely reason is that the labor

TABLE 6

Assumptions made in sample model runs

Assumptions	Community A	Community B	Community C
	Assumptions Specific to Communities		
1. Residents	50,000	100,000	25,000
2. Educational Level	Above avg.	Avg.	Below avg.
3. Annual MSW collection (tons)	25,000	45,000	12,000
4. Miles of city streets	125	275	75
5. Number of daily garbage truck routes	7	9	5
6. Workers on garbage truck crews	1	3	3
7. Crews paid by hour or route	Route	Hour	Hour
8. Size of garbage trucks (yards)	12	20	16
9. Hourly wage of service workers	$10.00	$10.00	$9.00
10. Side-load or rear-load trucks used for garbage pickup	Side	Rear	Rear

Assumptions Common to All Communities

11. Street patterns allow use of trailers if appropriate.
12. Work week for service workers is 40 hours.
13. All communities have a transfer station.
14. Pickup cost of refuse per ton is $70.00.
15. Hauling cost of refuse per ton is $20.00
16. Tipping fee for refuse per ton is $10.00.
17. Storage containers are free for recycling centers.
18. Basic processing machinery for centers is available free.
19. Space for recycling centers must be rented.
20. Space needs for pickup programs is free.
21. Space for garaging trucks and trailers is free.

TABLE 7

Summary of income and expense streams (in dollars) from most feasible option for each type of recycling mode, based on model runs

Dropoff-Donation Center

(All centers are geared for multi-material intake.)

Community	A	B	C
Scale of operation	Daily	Daily	Weekends
Tonnage collected	762.1	1,207.2	219.5
Sales of recyclables	29,161.69	46,192.12	8,398.57
Credit for reduced pickup expenses	5,334.66	8,450.10	1,536.38
Credit for hauling expenses avoided	15,241.88	24,143.13	4,389.66
Credit for tipping expenses avoided	7,620.94	12,071.57	2,194.83
Gross income from sales and credits	57,359.17	90,856.92	16,519.44
Number of workers (FTE)	1.8	2.9	1.6
Labor costs for the center	16,918.48	26,789.88	4,872.52
Gross costs	16,918.48	26,789.08	4,872.52
Net saving to community	40,440.69	64,058.04	11,646.92

Buyback Center

(All centers are geared for multi-material intake, daily operation.)

Community	A	B	C
Tonnage collected	1,270.2	2,172.0	560.9
Sales of recyclables	48,602.81	83,110.81	21,463.00
Credit for reduced pickup expenses	8,891.09	15,203.77	3,926.31
Credit for hauling expenses avoided	25,403.13	43,439.34	11,218.02
Credit for tipping expenses avoided	12,701.56	21,719.67	5,609.01
Gross income from sales and credits	95,598.59	163,473.59	42,216.34
Number of workers (FTE)	3.1	5.2	1.3
Labor costs for the center	28,197.47	48,217.67	12,452.00
Payouts for buyback of materials	24,301.41	41,555.41	10,731.50
Gross costs	52,498.88	89,773.08	23,183.50
Net saving to community	43,099.71	73,700.51	19,032.84

Municipal Curbside Pickup

(All programs collect two commodities: paper and mixed containers.)

Community	A	B	C
Type of operation	Racks	Trailers	Trailers
Tonnage collected	2,132.8	3,455.1	819.0
Sales of recyclables	46,732.40	75,706.48	17,945.25
Credit for reduced pickup expenses	0.00	0.00	0.00
Credit for hauling expenses avoided	42,656.00	69,102.72	16,379.90
Credit for tipping expenses avoided	21,328.00	34,551.36	8,189.95
Gross income from sales and credits	110,716.40	179,360.56	42,515.10
Annualized cost of equipment	600.00	1,800.00	1,000.00
Additional labor costs	10,429.00	10,429.00	9,386.10
Gross costs	11,029.00	12,229.00	10,386.10
Net saving to community	99,687.40	167,131.56	32,129.00

Municipal Curbside Pickup Plus Intermediate Processing

(All programs collect two commodities: paper and mixed containers.)

Community	A	B	C
Type of operation	Racks	Trailers	Trailers
Tonnage collected	2,132.8	3,455.1	819.0
Sales of recyclables	75,239.25	121,887.60	28,891.88
Credit for reduced pickup expenses	0.00	0.00	0.00
Credit for hauling expenses avoided	42,656.00	69,102.72	16,379.90
Credit for tipping expenses avoided	21,328.00	34,551.36	8,189.95
Gross income from sales and credits	139,223.25	225,541.68	53,461.73
Annualized cost of equipment	3,406.86	6,735.91	2,170.00
Additional labor costs	28,366.24	45,953.31	9,803.37
Gross costs	31,773.10	52,689.22	11,973.37
Net saving to community	107,450.15	172,852.46	41,488.36

TABLE 7 (continued)

Recyclables Pickup Licensed to Outside Contractor

(All programs collect two commodities: paper and mixed containers.)

Community	A	B	C
Tonnage collected	1,984.0	3,214.1	716.9
Sales of recyclables	0.00	0.00	0.00
Credit for reduced pickup expenses	13,888.00	22,498.56	5,332.99
Credit for haulinge expenses avoided	39,680.00	64,281.60	15,237.12
Credit for tipping expenses avoided	19,840.00	32,140.80	7,618.56
Gross income from sales and credits	73,408.00	118,920.96	28,188.67
Direct subsidy to contractor	15,872.00	25,712.64	6,094.85
Gross Costs	15,872.00	25,712.64	6,094.85
Net saving to community	57,536.00	93,208.32	22,093.82

supply for curbside pickup is already working for the community in its service department or in the sanitation crews of its refuse contractor. The level of recycling with an active pickup program is also typically about three times that of a dropoff-donation program. When it is easy for people to recycle, they will do so.

The model also has been used to investigate the impact of a bottle bill on recycling programs, specifically to determine the degree to which beverage container deposit legislation is "parasitic" on active recycling programs (Clapham 1985a). The results of this study demonstrate that deposit legislation does not reduce the net benefit of recycling programs. Indeed, it is unlikely to cause severe damage to a recycling program with an adequate resource base, since the economic base of most recycling programs is newspapers rather than beverage containers. The overall benefit to a community carrying out an active recycling program is increased substantially by beverage container deposit legislation, owing to the greatly increased participation level that characterizes communities with deposit legislation. The two approaches to recycling complement each other quite well and should be viewed as compatible tools for maximizing the results of expenditures for municipal solid waste management and for improving litter control.

SYSTEM REQUIREMENTS

RECYCLE has been implemented on an IBM Personal Computer in Microsoft Pascal. It requires 192 Kbytes of memory to run. It uses 174 Kbytes of disk space to store the model and its associated data files and an additional 34 Kbytes of disk space for files written during a run. In addition, RECYCLE requires WordStar and its MailMerge option to print the report from a summary file written by the model. Thus, the total disk space requirement for RECYCLE and all ancillary files is somewhat less than a single floppy disk on the IBM Personal Computer. A typical working session takes about five minutes.

OBTAINING AND USING 'RECYCLE'

RECYCLE is in the public domain and can be used by anyone. A complete listing is provided in the documentation prepared for the Office of Litter Control, Ohio Department of Natural Resources (Clapham 1984a, 1984b). Readers of this article may obtain a copy of this documentation or a disk containing the model at cost, or they may arrange to run the model for their community at their convenience. Interested parties should contact this author.

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APPENDIX: Mathematical Summary of the Model

Block I: Input

PTRC—Proportion of recyclable materials in MSW collections

TRC—Total tonnage of potentially recyclable MSW

TSWC—Total solid waste collections

$$TRC_i = PTRC_i * TSWC,$$

where i refers to newspaper, glass, ferrous metals, and aluminum.

Block II: Centers

Amounts

CRW — Anticipated collection of recyclable wastes by commodity
PR — Participation rate
TC — Total tonnage of collections for each option
TRC — Total tonnage of potentially recyclable MSW

$$CRW_{i,o} = TRC_i * PR_o,$$

$$TC_o = \sum_i CRW_{i,o},$$

where i is as before and o refers to the particular option under consideration.

Sales and Buyback Income and Expenses

BCRW — Total payout for purchase of recyclables in a buyback center
BV — Price paid for each commodity in a buyback center
CRW — Anticipated collection of recyclable wastes by commodity
PMV — Buyback payout price as proportion of the sale value of each commodity
SCRW — Gross income from sales of each commodity
SV — Sale value, by commodity
TSI — Total income from sales of recyclables
TBE — Total buyback expenditures

$$SCRW_{i,o} = CRW_{i,o} * SV_i$$

$$TSI_o = \sum_i SCRW_{i,o}$$

$$BV_i = PMV_i * SV_i$$

$$BCRW_{i,o} = CRW_{i,o} * BV_i$$

$$TBE_o = \sum_i BCRW_{i,o}$$

Credits

CH — Credit for savings in hauling from the transfer station to landfill
CHPT — Cost per ton for hauling refuse from transfer station to landfill
CP — Credit for cost reduction in neighborhood pickup
CPPT — Cost per ton for refuse pickup
CT — Credit for savings in tipping (i.e. disposal) of wastes
CTPT — Cost per ton for tipping wastes at the landfill
GI — Gross income
TC — Total tonnage of collections for each option
TSI — Total income from sales of recyclables

$$CP_o = TC_o * CPPT * 0.1$$

$$CH_o = TC_o * CHPT$$

$$CT_o = TC_o * CTPT$$

$$GI_o = CP_o + CH_o + CT_o + TSI_o$$

Costs

CC — Capital costs
ELC — Estimated lifetime of capital of recycling program
GC — Gross costs
LC — Total labor cost to the program
MW — Minimum wage
RS — Requirements for space
RW — Requirements for workers
SC — Annual cost of space for recycling center
SLD — Straight-line depreciation on capital,
SRNT — Space rental per unit area
TBE — Total buyback expenditures
WY — Workyear in hours per year

$$CC_o \ \alpha \ TC_o$$

$$SLD_o = CC_o/ELC$$

$$RW_o \ \alpha \ TC_o \text{ (minimum 1)}$$

$$LC_o = RW_o * WY_o * MW$$

$$RS_o \ \alpha \ TC_o \text{ (minimum 350 sq. yd)}$$

$$SC_o = RS_o * SRNT$$

$$GC_o = TBE_o + SLD_o + LC_o + SC_o$$

Net Savings

GC — Gross costs
GI — Gross income
NET — Net savings from the center

$$NET_o = GI_o - GC_o$$

Block III: Pickup

Amounts

CRW — Anticipated collection of recyclable wastes by commodity
PR — Participation rate
TC — Total tonnage of collections for each option
TRC — Total tonnage of potentially recyclable MSW

$$CRW_{i,o} = TRC_i * PR_o,$$

$$TC_o = \sum_i CRW_{i,o},$$

where i and o are as in the previous block.

Sales Income

CRW — Anticipated collection of recyclable wastes by commodity
SCRW — Gross income from sales of each commodity
SV — Sale value, by commodity
TSI — Total income from sales of recyclables

$$SCRW_{i,o} = CRW_{i,o} * SV_i$$

$$TSI_o = \sum_i SCRW_{i,o}$$

Credits

CH — Credit for savings in hauling from the transfer station to landfill
CHPT – Cost per ton for hauling refuse from transfer station to landfill
CP — Credit for cost reduction in neighborhood pickup
CPPT — Cost per ton for refuse pickup
CT — Credit for savings in tipping (i.e. disposal) of wastes
CTPT — Cost per ton for tipping wastes at the landfill
GI — Gross income

TC — Total tonnage of collections for each option
TSI — Total income from sales of recyclables

$$CP_o = 0.0 \text{ for rack and trailer-based systems; otherwise } CP_o = TC_o * CPPT * 0.1.$$

$$CH_o = TC_o * CHPT \text{ if there is a transfer station; otherwise } CH_o = 0.0.$$

$$CT_o = TC_o * CTPT$$

$$GI_o = CP_o + CH_o + CT_o + TSI_o$$

Costs

AME — Base annual truck maintenance expense
AVN — Average velocity (truck mi/hr) needed to service the entire community
AVF — Average velocity possible for a real "cruising" recycling truck
AW — Average annual wage paid to sanitation workers
CCI — Capital costs for intermediate processing equipment
CCS — Capital costs for storage
CCP — Capital related to the actual pickup of recyclables
CG — Per-gallon cost of gasoline
CRT — Per-truck cost of racks or trailers
CT — Credit for savings in tipping (i.e. disposal) of wastes
CTR — Price of a truck used for separate recyclables pickup
DC — Dropoff cost
ELCI — Life expectancies of capital invested in intermediate processing
ELCP — Life expectancies of capital invested in pickup
ELCS — Life expectancies of capital invested in storage
GAS — Gasoline costs
GC — Gross costs
GT — Number of garbage trucks used in standard MSW pickup
LTF — Daily cost of dropping off materials at recycling transfer facility
MLC — Marginal labor costs of the recycling operation
MPG — Truck's gas consumption in miles per gallon
MT — Number of miles to be travelled each week
PTF — Proportion of the tipping fee saved by recycling granted as subsidy
RS — Requirements for space
RSC — Basic refuse service cost
RTR — Number of trucks required for separate-truck recycling programs
RW — Requirements for workers
SC — Annual cost of space for storing recyclables
SCE — Cost of space for equipment storage
SENT — Cost of space per unit area in equipment storage area
SLD — Total straight-line depreciation on capital
SLDI — Straight-line depreciation on investment in intermediate processing
SLDP — Straight-line depreciation on investment in pickup equipment
SLDS — Straight-line depreciation on investment in storage facilities
SRE — Additional space needed to store equipment involved with collection
SRNT — Space rental per unit area in recyclables storage area
STR — Storage requirements per trailer
STK — Storage space needed per truck
SUP — Financial support for licensee pickup of recyclables
TC — Total tonnage of collections for each option
TCS — Crew size of each truck
TOM — Truck operating and maintenance costs
TS — Time surcharge to load recyclables into trailers on side-loading trucks
TSM — Community's total street mileage
WDY — Number of workdays in a year
WW — Working hours in a week
WS — Wage surcharge

For systems based on all methods of pickup

$$CCS_o \propto TC_o$$

$$RSC = GT * AW * TCS$$

$$RS_o \propto TC_o$$

$$SC_o = RS_o * SRNT$$

$$SUP_o = PTF * CT_o \text{ if pickup is licensed to third party; otherwise } SOP_o = 0.0.$$

For systems based on racks and trailers

$$DC_o = GT * WDY * LIF_o \text{ if community has no transfer station; otherwise } DC_o = 0.0$$

$$CCP_o = GT * CRT_o$$

$$WS_o = 0.0 \text{ if crews are paid by the route; otherwise } WS_o = 0.02$$

$$TOM_o = 0.0$$

For rack-based systems

$$MLC_o = RSC * WS_o$$

$$SRE_o = 0.0$$

For trailer-based systems

$$TS_o = 0.0 \text{ if garbage trucks load from the rear; otherwise } TS_o = 0.02$$

$$MLC_o = RSC * (WS_o + TS_o)$$

$$SRE_o = GT * STR$$

For systems based on separate trucks

$$DC_o = 0.0$$

$$MT_o \propto TSM$$

$$AVN_o = MT_o/WW$$

$$RTR_o = AVN_o/AVF \text{ (minimum 1)}$$

$$CCP_o = RTR_o * CTR_o$$

$$GAS_o = MT_o * 52 * CG/MPG$$

$$TOM_o = GAS_o + (AME_o * RTR_o)$$

$$MLC_o = RTR_o * AW$$

$$SRE_o = RTR_o * STK$$

For systems based on all methods of pickup

CCI_o α TC_o for systems with intermediate processing; otherwise $CCI_o = 0.0$

$$SLDS_o = CCS_o/ELCS$$

$$SLDP_o = CCP_o/ELCP$$

$$SLDI_o = CCI_o/ELCI$$

$$SLD_o = SLDS_o + SLDP_o + SLDI_o$$

$$SCE_o = SRE_o * SENT$$

$$GC_o = TOM_o + SLD_o + MLC_o + SC_o + SCE_o + DC_o + SUP_o$$

Net Savings

GC — Gross costs
GI — Gross income
NET — Net savings from the center

$$NET_o = GI_o - GC_o$$

Block IV: Ranking

$$NET_c = \max (NET_o),$$

where *o* is as before and *c* refers to the options chosen. The term max refers to the two maximum values for each type of operation.